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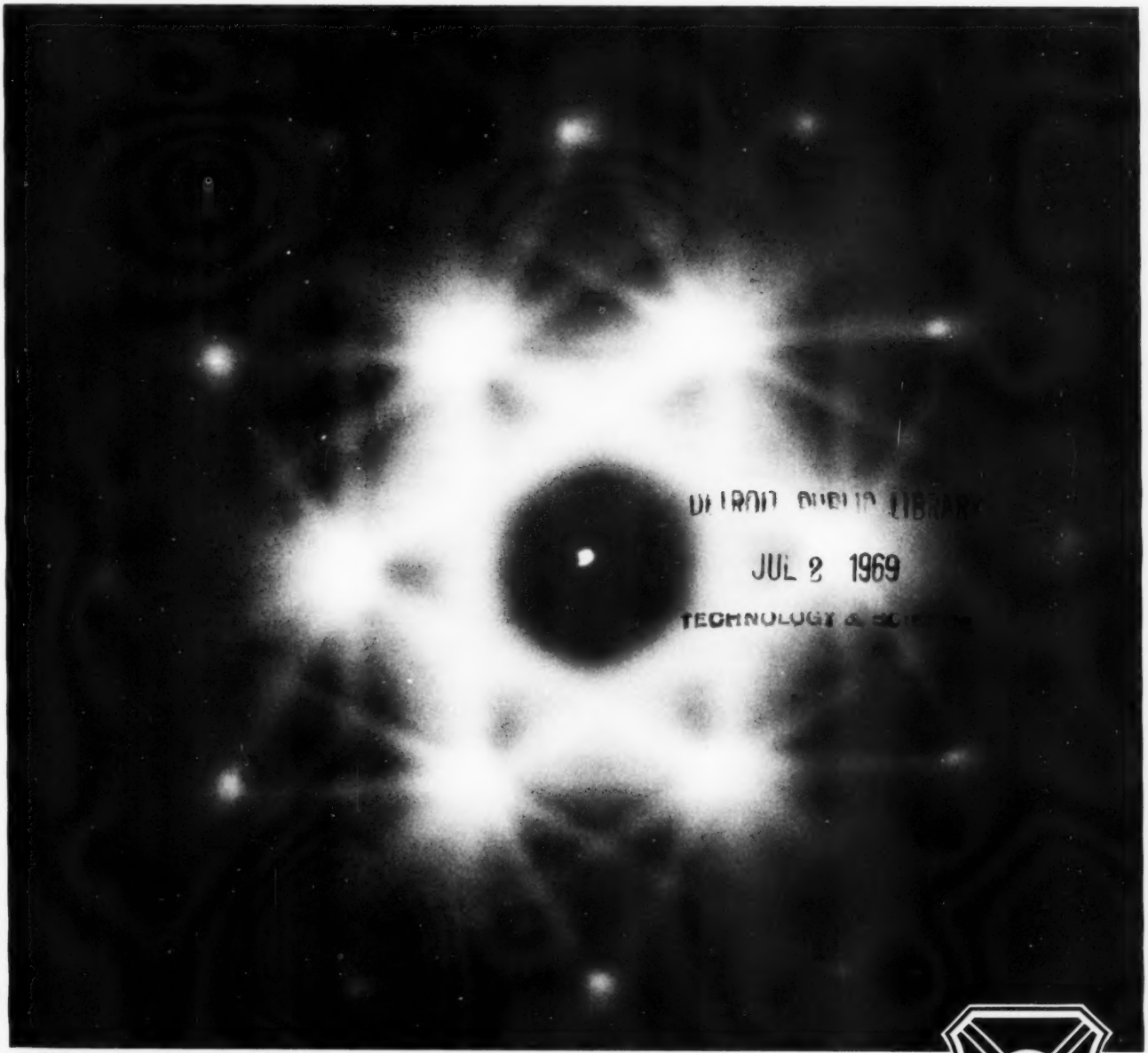
OAR RESEARCH REVIEW

OFFICE OF AEROSPACE RESEARCH ★ UNITED STATES AIR FORCE



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OAR RESEARCH REVIEW

VOLUME VIII NUMBER 3 May-Jun 1969

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ON THE COVER:

The cover photograph shows an electron-diffraction pattern made by Joseph Comer of the Solid State Sciences Laboratory, AFCRL. This particular form is known as the Kikuchi pattern, first observed by the Japanese physicist. It shows the orientation of atoms in a silicon lattice with a 111 orientation. To make the pattern, the silicon is thinned so that the electron beam passes through the material, a process known as transmission electron diffraction.

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JACOB SEIDEN *Editor*

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OARRP 80-1

transverse waves on detonations

DR. ROGER A. STREHLOW and DR. HAROLD O. BARTHEL
University of Illinois, Urbana

The maximum speed of aircraft with air-breathing engines continues to increase. When this maximum speed approaches the hypersonic flight regime, the fuel will have to be burned in a supersonic stream. The supersonic stream must exist in order not to exceed the maximum temperature for sustained engine operation using present-day engine materials. This supersonic flow requirement in the engine leads to two limitations on the allowable reaction rates. One limit is obtained by requiring that burning be completed prior to discharge from the engine, for to do otherwise would result in a loss of efficiency. The other limit is obtained by requiring that the reaction does not take place so fast that it leads to a detonation wave, since in this case the flow becomes subsonic, and very high pressures and temperatures are produced. Both of these results are undesirable.

Detonation waves in confined spaces have been found to contain a complex frontal structure.(1) This structure consists of numerous irregular cells on the front formed by intersections between the front and many transversely propagating shock waves. Usually, these transverse waves are relatively weak, having a normal Mach number of less than 1.5. Further, each wave in the neighborhood of its interaction with the incident shock may be considered to be a simple Mach stem interaction. Indeed, this portion of the structure has been found to obey the laws of hydrodynamics under the assumptions that (a) the interaction point is steady in a co-ordinate system which moves with the interaction point, and (b) the flow is unreactive on both sides of the slipstream which arises at the interaction.(3,4)

Nevertheless, energy from the reaction is being released behind the transverse waves. In fact, this energy release is necessary to sustain the transverse waves. This driving mechanism is in marked contrast to the usual Mach interaction in which the transverse wave is sustained because of boundary conditions which must be satisfied at the wall or within the stream.

An examination of records which reveal the nature of the detonation front shows that (a) the waves usually move in many different directions across the shock front, and (b) the waves moving in a particular direction form a train of waves. Obviously, the crossing of these trains of waves moving in different directions will cause the strength of a local element of the shock front to vary with time. The particular variation depends not only upon the time the waves last crossed the element, but also upon the wave orientations as the crossings took place.

The spacing of the wave trains has been found to be dependent upon the particular chemical system and upon the pressure within the system.(5,6) The chamber size seems to have little or no effect if it is large compared to a cell dimension. The great interest in these spacings arises from the possibility that their regular nature may excite resonant instabilities, which in turn may lead to large-amplitude destructive disturbances.

The source of these transverse disturbances is not known, although there is some experimental evidence that they grow from acoustic waves.(2) Another unknown is the particular effect of heat release on the interaction, i.e., the interaction of the chemical kinetics with the fluid dynamics. Finally, the major question has to do with why ordinary detonations are self-sustaining.

From the previous description of the structure, the great difficulty involved in making a meaningful study of this phenomenon must be evident. Clearly, the interaction effects of many waves must be eliminated. What is needed is an isolated transverse wave which can be easily controlled and observed.

With the support of the Air Force Office of Scientific Research, work has been conducted in the shock-tube laboratory of the Aeronautical and Astronautical Engineering Department at the University of Illinois. In this research, two methods of generating the transverse wave were considered. The first and seemingly most promising method considered was to generate a single transverse wave behind an intitially unreactive shock wave by passing the shock wave over a ramp in a shock tube. The ramp angle was set so that, for a given incident shock strength, a Mach stem interaction would occur with the temperature behind the Mach leg being high enough to initiate the reaction within the field of view of an interferometer. The second method considered involves suppressing the transverse waves on a self-sustaining detonation by passing it through a converging-diverging section.(3) The now-smooth and diverging reactive shock wave is passed over a ramp to generate a single transverse wave of known amplitude. Figure 1 shows a schematic diagram of the ramp geometry and the location of the shock-tube window relative to this ramp. The tube is instrumented with a Mach-Zehnder

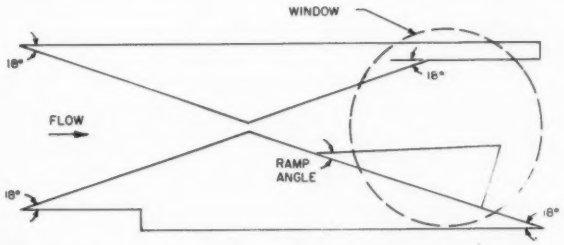

Figure 1. Schematic drawing of nozzle ramp arrangement for the Department's 4" x 15" shock tube. The window location relative to the ramp is also illustrated. With the proper initial conditions, this nozzle design will convert an ordinary propagation of detonation into an overdriven "laminar" detonation so that an isolated Mach stem may be produced on the ramp and studied using the interferometer.

interferometer which may be used to record a single spark interferogram of the flow field at any instant during the interaction.

Using a hydrogen-oxygen system, the first method has been tried for a number of geometries and shock strengths. All of these efforts have failed, largely because the ignition lag time behind the Mach stem could not be made short enough to overcome attenuation loss and ignition lag problems behind the incident shock. The studies are now proceeding using the second method. Figure 2 contains two typical interferograms obtained with this method using a green light filter (5177 Å), and shows the structure of a reactive Mach stem on a 20° and 30° ramp. Notice that the 30° ramp structure is considerably more complex, containing a second interaction on the reflected shock wave. More complex Mach stem structures are observed on detonation fronts when the transverse wave system is strong; and in an isolated Mach stem experiment using ramps, a 30° ramp will produce a stronger Mach stem configuration than a 20° ramp. The reason for these different behaviors in our experiment is now being investigated in detail.

At the same time, a theoretical investigation of the interaction behavior of single, finite-amplitude, transverse waves is under way, since it is now known that acoustic theory predicts spacings which are a factor of approximately 50 times too small when compared to the experimentally measured spacings. This theoretical study of finite transverse waves is presently limited to an investigation of the crossing of two transverse waves of equal strength and opposite families in an unreactive flow. The purpose of this study is to determine whether the interaction is a steady phenomenon. If the result is found to be unsteady, then this additional effect must be taken into account when considering the reaction effects in the analysis.

These experimental and theoretical studies seek to fill a gap in our fundamental knowledge. The results should be useful as a guide to the development of applied design principles as well as in their application to advanced propulsion systems.

Dr. Roger A. Strehlow is Professor of Aeronautical and Astronautical Engineering at the University of Illinois, Urbana. He received his Ph.D. in Physical Chemistry from the University of Wisconsin in 1950, and subsequently worked for the Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland as a research chemist. He finished his tenure there as Chief of the Physics Branch, IBL. In 1960 he visited the University of Illinois as a Ford Foundation Visiting Professor, and joined the faculty in his present position in 1961.

Dr. Strehlow's research has been devoted to the field of reactive gas dynamics, including the use of shock tubes, studies of flame propagation, solid-propellant instabilities, and the initiation of detonation. His most recent research has centered around studies of detonation structure. He is the author of the textbook, Fundamentals of Combustion, published in 1968.

Dr. Harold O. Barthel is Associate Professor of Aeronautical and Astronautical Engineering at the University of Illinois, Urbana. Following military service in the Navy in World War II, he completed his studies in Mechanical Engineering at the University of Illinois, receiving the B.S. degree in 1950, the M.S. degree in 1951, and the Ph.D. degree in 1957. He joined the Aeronautical and Astronautical Engineering Department in 1954 as a Research Associate. Dr. Barthel's research has been devoted largely to unsteady gas dynamic flows with particular emphasis upon shock-tube flow.

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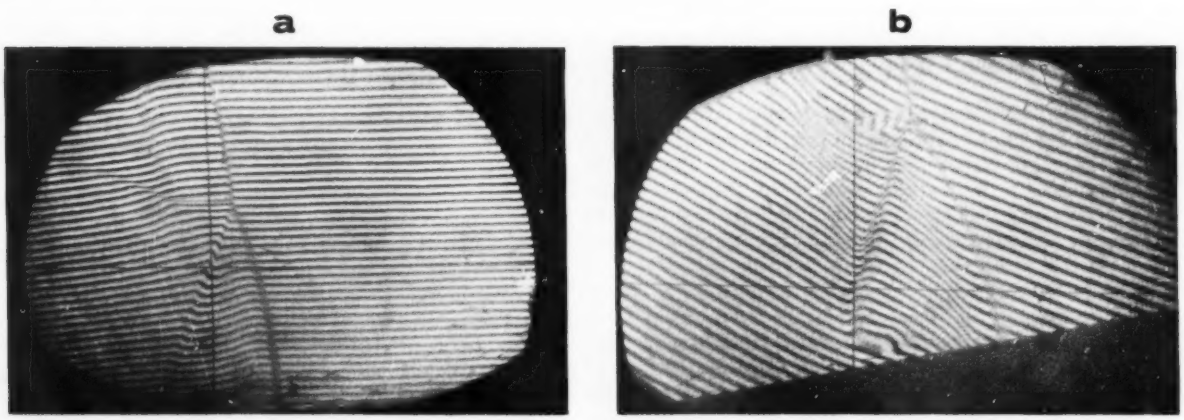


Figure 2. Two photographs obtained using spark interferometic photography:
a) ramp angle = 20°; b) ramp angle = 30°. Both photographs were obtained in a mixture of 70% argon, 20% hydrogen plus 10% oxygen, under conditions when the Mach stem flow is fully reactive. Notice the much more complex flow structure in the case of the 30° ramp.

ORIGIN of the SOLAR SYSTEM

SPACE PHYSICS LABORATORY
AFCRL

Most of the stars of the universe have planetary systems similar to our own, with an array of planets extending outward along the equatorial plane of a central sun. This is the implication of a theory presented by Marvin L. White of AFCRL in his paper, "Origin of the Solar System," presented at the American Astronomical Society, Austin, Texas, in December 1968.

In his paper, White presents a new theory for the origin of the solar system. This theory explains the forces that originally set in motion the stately procession of the earth and its sibling planets about the sun--all revolving in endless pirouettes. It also explains why each planet is separated from its neighbor at a mathematically related distance, with the separation interval increasing with increasing distance from the sun. In support of the theory, White presents observational evidence of momentum-conservation mechanisms in our atmosphere and on the visible surface of the sun, the photosphere. He shows that these mechanisms can be simulated with fluids in laboratory experiments.

As a starting point, White borrows certain concepts that astrophysicists have considered for many years. He starts with a rotating protosun, a vast cloud of gas and dust that extends out beyond the borders of the present planetary system. He then assumes a temperature gradient between the center of the dust-and-gas cloud and its periphery. Given the condition of a rotating cloud and convections within the cloud due to temperature differentials, winds are created in the cloud. These winds, in turn, produce vortex systems. Thus, each of the planets, according to White's theory, originated as a vortex system in the gas and dust of the protosun.

Many astrophysicists have considered the possible connection between vortex systems and planet formation--the first such suggestion dating back to Descartes in 1644--so the vortex concept is hardly new. But those who have tried to develop a model based on the concept have found themselves faced with difficult physical constraints. The basic problems have been angular momentum conservation and transfer.

For example, a large vortex system should quickly (in a matter of days) dissipate its momentum in smaller eddies. But this fact was in conflict with calculations showing that it should take a billion years or so for a vortex system to concentrate dust into a planetary core. The vortex system would have to be much more efficient than this for a very simple reason. It took, according to other calculations, only about 30 million years for the gas and dust of the protosun to contract into a functioning sun. Very well. Let's suppose that we have worked out all these problems. We would then have to explain how the newly formed planets achieved the velocity to remain in solar orbit.

White's theory overcomes these difficulties. He has derived an elegantly consistent model of the formation of the solar system. The theory borrows heavily from studies of atmospheric circulations and, in particular, from a certain peculiar wave structure, known as long waves or Rossby waves, that serve to explain certain effects in the earth's atmosphere and on the photosphere, the visible surface of the sun. These wave structures have been simulated for many years in the laboratory with the use of rotating fluids. These laboratory experiments are called dishpan experiments.

In dishpan experiments, two fluid motions are established. One is rotational; the other, perpendicular to the first, is convective and results from a temperature differential in the fluid. A structured wave is formed. That the wave has structure and order is a critical feature of the model. It is this order which permits the "uphill" transport of momentum from smaller units to larger ones. Were the turbulence created by the two fluid motions random, large-scale systems could not be sustained. Although the wave structure may curl to form small eddies, these smaller eddies can still transport energy (and the material they have accreted) into a larger vortex system. The large vortex system can be sustained for millions of years.

This "uphill" transport of energy observed in fluids is used to explain two seemingly disparate phenomena in the atmosphere and on the solar photosphere. One of these is the fact that the sun rotates faster at its equator than it does at its poles--about 25 days and 31 days, respectively. Many astrophysicists now believe that an ordered wave structure, the saw-toothed Rossby waves, not only sustains the faster equatorial rotation, but also accounts for the paths of sunspots which form at the middle solar latitudes and drift toward the solar equator. The other phenomenon is the jet stream in the earth's atmosphere. The jet stream can reach sustained velocities of more than 370 miles an hour, a phenomenon now explained on the basis of a structured wave system permitting the large jet-stream system to gather momentum from smaller ones.

With this as background, let's look more closely at White's theory on the

origin of the solar system. White postulates that jet streams developed in the dust and gas along the equatorial plane of the protosun. Dust particles from the higher protosun latitudes drifted down into the streams, just as we see sunspots drifting from high latitudes to the more rapidly rotating solar equator. Eddies and vortexes form in this stream because of velocity differences between adjacent flow fields. Because of the ordered and structured nature of the total energy system, momentum is transported from smaller eddies to a larger-scale vortex. White states that, given the proper temperature differential within the dust-and-gas cloud, several equatorial jet streams developed at certain quantized distances from the center of the cloud.

The basic equation of White's theory states that the radii of successive boundary lines between neighboring jet stream–vortex systems form a simple geometrical progression with each being a constant factor larger than the previous one. Within each of the boundary regions, the growing vortex accretes dust and gas, sustained by the energy from smaller systems. The system is highly stable.

When the remaining dust and gas of the protosun contract inward into the newly forming sun, the material that had once formed the core of a vortex is left behind and exposed, now that the obscuring blanket of dust has cleared away. It had been accelerated to orbital velocities by the jet stream in which it had formed. Its rotation is the vestige of the vortex that gave it birth. White, in his paper, also deals with the formation of the moons of the planets. When the planets have several moons, the moons are also separated by mathematically related intervals.

The more massive Population I stars, White believes, were unable to form planetary systems because critical mass, pressures and temperatures increased too rapidly, vaporizing the dust before it could be concentrated. Such stars are observed to have extremely high rotational velocities, indicating that, after contraction from protostar to star, they retained all the angular momentum of the material forming the original cloud. Most of the angular momentum of our solar system, on the other hand, is retained by the planets, and thus our sun has a relatively slow rotation velocity. Stars below a certain critical size all seem to have rotational velocities comparable to that of our sun--evidence that their angular momentum is distributed in planetary systems.

Mr. Marvin L. White is a research astrophysicist with the Space Physics Laboratory, AFCRL. He attended the University of Texas where he received a B.A. in Physics in 1940. He also holds a Master's degree in Physics from the University of Missouri.

Mr. White enlisted in the U.S. Signal Corps at the start of World War II. After approximately four years in the service, he worked for the Army Map Service in astrogeodetics. The purpose of this work was to obtain an accurate intercontinental distance. He did some field work in the Azores at that time. In 1952 Mr. White went to work at the National Bureau of Standards, and eventually joined AFCRL in January 1961.

Currently, Mr. White has been studying the physics of the solar atmosphere and interplanetary climatic conditions. He has received a grant from the Director's office to simulate the solar corona in a dishpan, and has monitored two contracts with the Lowell Institute of Technology Research Foundation. He has a number of papers to his credit.

Marvin L. White, whose theory on the origin of the solar system appears in the accompanying text, is the author of many papers on the solar atmosphere and magnetic fields.

RENAISSANCE OF MICROWAVE ACOUSTICS

MICROWAVE PHYSICS LABORATORY, AFCRL

Microwave-acoustics research will, within the coming decade, provide the foundation for a new technology. The purely electronic circuitry of military and civilian products will increasingly give way to electroacoustic components. This, at any rate, is the prediction of a small but growing number of microwave acoustic researchers.

The ones likely to be most skeptical of this prediction are those who last surveyed the field about two years ago when potential applications appeared distant. The scene has suddenly changed with new emphasis on the surface transmission of acoustic waves as opposed to past emphasis on transmission through the bulk material.

Microwave acoustics involves the manipulation of elastic waves in a material. The waves propagate along the optically polished surface of a solid material just as they would on the surface of a liquid. The research is conducted under many labels--ultrasonics, phonon research, hypersonics and most recently, praetersonics--but the designation, "microwave acoustics," is emerging as the preferred term.

Microwave acoustic devices can perform most of the functions of purely electronic devices. They can do it in smaller packages since the acoustic velocity and wavelength are five orders of magnitude smaller than their electromagnetic counterparts. Complex signal processing, amplification and filtering can all be done. Acoustic materials can also serve as waveguides, delay lines and isolators.

AFCRL started its microwave-acoustics program in 1958, and was then almost alone in the field. Even today fewer than 25 research groups have committed themselves to microwave-acoustics programs (as against many who are looking on with interest or perhaps beginning to wet their feet). As with most new technologies, much must be done, and on many fronts. The search for optimum microwave acoustic materials (lithium niobate is presently among the forerunners) is important; but the biggest single problem is the transducer problem--converting electrical and acoustical energy back and forth with a minimum loss of signal during the process. Then there is also a separate class of problems of particular concern to the researcher--that of developing experimental and analytical techniques.

Dr. Paul H. Carr and Lt. Andrew J. Slobodnik of AFCRL have recently developed a new technique for measuring the surface losses in microwave acoustic materials. As the waves propagate along the surface of a material, they diminish in strength. The basic measure of merit of a microwave acoustic material is, therefore, its loss rate with propagation distance. Different materials, of course, have different loss rates. But loss rates also result from microscopic pits and defects, thermal scattering, and foreign substances on the surface of the material. With the present state-of-the-art, it is necessary to characterize the propagation properties of each sample of a given material as well as of those of different materials.

The Carr–Slobodnik technique uses a 1-millimeter-diameter laser beam directed at the surface of the material at roughly a 45-degree angle. In addition to the specular reflection, the surface wave acts as a moving diffraction grating which deflects the light into a number of side lobes at angles prescribed by scattering theory. This deflected light is detected by a photomultiplier. Slobodnik has measured surface-wave attenuation of lithium niobate at various frequencies up to 2-GHz by scanning the laser along the material.

The laser technique promises to become one of the standard methods for analyzing the properties of microwave acoustic materials.

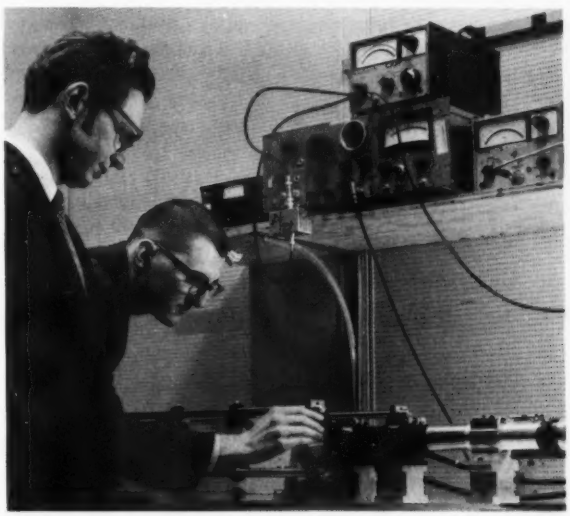
Dr. Paul H. Carr is a supervisory research physicist (solid state), and Chief of the Microwave Acoustics Branch, Microwave Physics Laboratory, AFCRL. He received both his B.S. in Physics (1957) and his M.S. in Physics (1961) from M.I.T., and his Ph.D. in Physics (1966) from Brandeis University.

Previously Dr. Carr was a research associate during the summers of 1958 and 1959 at Lincoln Laboratory. In October 1961, after entering on his tour of active duty with the Army as a 1st Lt, he was assigned to the Army Missile Command Calibration Center as a research physicist. Here he worked on new techniques for the calibration of accelerometers, infrared and optical detectors, and vacuum gauges.

Currently, Dr. Carr is making use of microwave phonons for extending the fundamental knowledge of solid-state phenomena and for use in microwave delay line applications. These efforts are directed towards studying the phonon-phonon interactions and the detection of microwave phonons by photon-phonon double-quantum transitions in paramagnetic ions.

Dr. Carr is a member of the American Physical Society, and an associate member of Sigma Xi. He has a number of publications to his credit.

Lt Andrew J. Slobodnik, Jr. is assigned to the Microwave Acoustics Branch, Microwave Physics Laboratory, AFCRL, where he is presently engaged in microwave acoustic surface-wave research. He received his S.B. and S.M. degrees in Electrical Engineering from M.I.T. in 1966. He then entered the Air Force through Officers Training School in 1967 after an additional year of graduate study at the University of California, Berkeley.



Dr. Paul H. Carr (left) and Lt Andrew J. Slobodnik realign their laser analytical equipment used to detect the attenuation of an acoustic wave along the surface of a material.

the nature of turbulence in the mixing of binary gases in flowing systems

STEPHEN ZAKANYCZ, Aeronautical Systems Division, AFSC, and DR. WILLIAM C. ELROD and DR. HAROLD E. WRIGHT, Mechanical Engineering Department, AFIT

The mixing of gases is a fundamental and essential part of many propulsion devices. Chemical reactions, cooling processes, and thrust augmentation involve mixing over a range of velocities from low subsonic into the supersonic regime. Studies *at the Air Force Institute of Technology (AFIT) are directed toward establishing the influence of geometric and flow parameters on the mixing process. These include the mixing of a single stream with the surrounding secondary flow and the mixing of many streams in parallel flow over a wide range of velocity ratios. Schlieren optical techniques and physical sampling techniques are employed to examine the effectiveness of mixing. Hot-wire anemometry and Pitot tubes are used to investigate the velocity, pressure, and velocity fluctuations associated with the flow streams.

A multijet mixing device geometrically similar to one used at the Carnegie Institute of Technology for chemical kinetic studies has been fabricated to investigate the mixing of two fluids. The design, shown in Figure 1A, allows the two fluids to flow from alternate tubes, as shown in Figure 1B, at velocities up to Mach 1. The present effort includes: investigation of the velocity, static pressure, and total pressure distributions at various flow conditions of the two fluids, as well as a detailed study of the relation between the flow from the individual tubes and properties of the total combined flow stream. The objective is to relate the flow parameters for the individual streams to the quality of mixing achieved in the combined flow stream. Figure 2 shows the variation of total pressure for individual flow streams with axial distance from the exit face. Further, the curves presented indicate the variation of total pressure with radial displacement from the centerline (i.e., three locations - inner, intermediate and outer). Substantial changes from the centerline exit-face pressure occur at locations reached by radial or axial movement. The significance of these effects will become clearer as information is obtained on velocity and static-pressure distribution and on the behavior of the total flow stream.

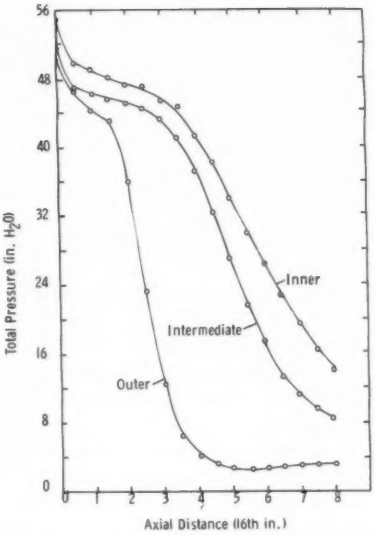


Figure 2. Axial and radial pressure profiles.

The mechanism and physical characteristics of mixing a gaseous fuel with air at flow velocities up to Mach 1.5 has also been studied extensively. The experimental apparatus was a two-dimensional mode of a single fuel

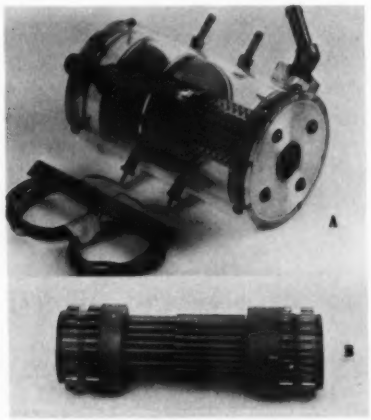


Figure 1. (A) Multijet mixing device. (B) Tube bundle assembly.

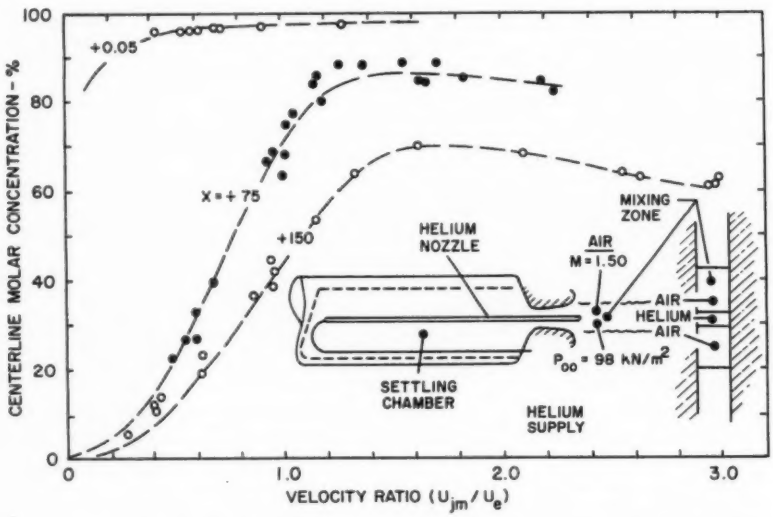


Figure 3. Coaxial jet-mixing device, schematic of device and centerline molar concentration for a range of velocity ratios (courtesy of A. Watton).

These studies are supported by an OAR-AFIT agreement whereby OAR has provided essential funding for this research.

jet discharging into a high-velocity air stream as shown in Figure 3. The flow conditions and the geometry of the model were established to represent a fuel injector in a supersonic combustion ramjet engine. Mixing of the gaseous fuel with the supersonic air stream occurs in a turbulent diffusion process. While combustion in a supersonic stream has been accomplished in the laboratory, the difficulties involved have prompted further detailed study of the flow phenomena.

The behavior of the primary flow around the fuel nozzle with and without a fuel flow was examined carefully (helium is used to simulate gaseous hydrogen fuel). Similarly, a gaseous flow through the fuel nozzle was investigated. A study was made with concurrent flow streams to determine the degree of mixing over a range of fuel-to-air velocity ratio (u_{jm}/u_e) from 0 to 3. The degree of mixing as given by molar concentration of helium on the centerline at various distances, X, from the beginning of mixing varies sharply at low values of velocity ratio as shown in Figure 3. However, above a value of 1.4, the velocity ratio has little influence on the centerline mixture concentration at a particular location. At velocity ratio greater than 1.0, the centerline molar concentration appears to reduce approximately linearly with increase of distance. Hence, for large velocity ratio, long mixing lengths may be required. Typical schlieren pictures of the interaction between primary flow and secondary flow are shown in Figure 4 for helium-to-air ratios of 1.3 (A), 1.5 (B), and 2.3 (C).

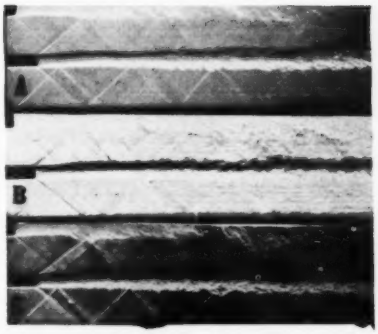


Figure 4. Schlieren photographs of air-helium mixing for helium-to-air velocity ratios of 1.3 (A), 1.5 (B), and 2.3 (C) (courtesy of A. Watton).

THE HUMIDITY CONTROVERSY

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

The British and the Americans have disagreed about stratospheric humidity for many years. The British view is that the stratosphere is uniformly dry. Until fairly recently they had found no evidence in their extensive and long-term high-altitude aircraft measurement program that would cause them to modify their position.

One American view--particularly that of AFCRL scientists who, over the years, have made hundreds of humidity measurements from balloons, rockets and aircraft--is that the moisture content of the stratosphere is not uniform and is sufficiently high to affect infrared observations. Furthermore, even in the region above the stratosphere, the mesosphere, between 50 and 80 km, contains some moisture. This subject is reviewed in the report, "Humidity Up to the Mesopause," (AFCRL-68-0550) by Norman Sissenwine, Donald D. Grantham and Henry A. Salmela.

The question of humidity in the upper air is important to the Air Force for several reasons. For meteorology, the presence of nonuniformly mixed water vapor at high altitudes could lead to local modifications of the circulation pattern, since it could account for the absorption of solar energy in the infrared spectrum. The resulting differential heating would lead to pressure gradient changes and these, in turn, would lead to changes in the wind field. From an astronomical viewpoint, the water vapor in the stratosphere must be known when observations of the atmospheric constituents of other planets are made from balloons in the earth's stratosphere. An unexpected amount of water vapor could affect the performance of infrared devices when used in the stratosphere, and could also affect the performance of horizon-sensing instrumentation used for spacecraft.

The British theory is that the tropopause (that point in the upper atmosphere found between about 12 and 18 km where temperatures stop decreasing with altitude and begin to increase again) acts as a cap to water vapor rising up from the earth's surface.

AFCRL scientists, on the other hand, present a number of possible mechanisms whereby moisture can penetrate the tropopause and enter the stratosphere. They cite data on stratospheric humidity collected from humidity sensors carried aboard many balloons and rockets. Such measurements should be conclusive, but they are not. The problem is contamination. Even if one launches a completely moisture-free vehicle, it will still pick up moisture during transit through the troposphere. This small amount of moisture, when released in the stratosphere, could invalidate measurements.

The AFCRL scientists, in their report, consider all these matters from a variety of standpoints. With respect to contamination, the strongest evidence shows that hygrometers sent aloft do, in fact, measure stratospheric moisture and not moisture transported there by the vehicle (with which elaborate precautions are taken). (See Figure 1) This evidence is a peak of moisture concentration frequently observed at about 25 km. This peak has been observed many times on both the upward trajectory of the vehicle and during its descent.

Another strong piece of evidence presented relates to noctilucent cloud particles. Such clouds are observed at northern latitudes at mesopause altitudes of about 80 km. Since 1962, AFCRL has sent a number of rockets into these clouds and has collected noctilucent cloud particles for examination. AFCRL has found that about 20 percent of the microscopic particles collected were ringed by a halo-like structure, believed to be caused by water or

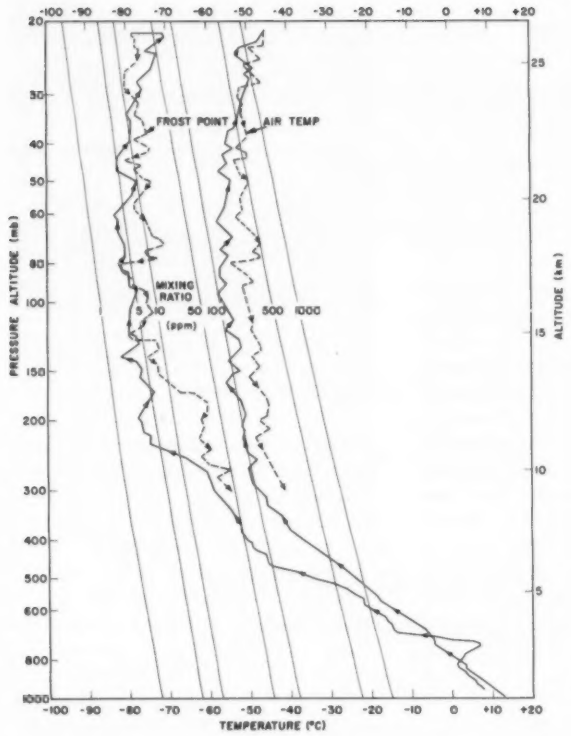


Figure 1. Balloon sounding, 22 April 1965, at Chico, California. In this case the air encountered in ascent was actually drier than that encountered in descent in the stratosphere and upper troposphere. During the several hours of flight, the balloon had moved a considerable distance across a mountain range, and was sampling a different air mass. The figure shows the horizontal stratification (layering effect) in the frost-point profile. Several lamina are observed on both ascent and descent portions of the sounding. Examples are the layers at 140 and 50 mb. These stratified layers range in depth from a few hundred meters up to over a kilometer.

ice that surrounded the particle prior to impact with the collecting surface.

However, the AFCRL case for relatively high humidity in the upper air is fundamentally analytical. From considerations of mixing ratios, vapor pressure, temperatures, and frost points, and the application of these considerations to a particular series of 17 balloon-sounding measurements from Chico, Calif., the AFCRL scientists have developed a model of humidity up to the mesopause. This model, and the humidity values as a function of altitude that are derived from it, promise to establish a standard reference for designers of upper-air research instrumentation and operational equipment subject to the influence of humidity.

Mr. Norman Sissenwine is Chief of the Design Climatology Branch, Aerospace Instrumentation Laboratory, AFCRL. He has attended Pratt Institute, the George Washington University, the Johns Hopkins University, the University of Alabama, New York University, and the University of Puerto Rico (under auspices of the University of Chicago). Much of this schooling was on a part-time basis while Mr. Sissenwine was working in the Federal Government. He was awarded the Degree of Bachelor of Science in Meteorology "with distinction" by New York University in 1948.

Mr. Sissenwine enlisted in the Aviation Cadets following the Japanese attack on Pearl Harbor, and was called to active duty in August 1942. He served his cadet tour at N.Y.U., was commissioned in May 1943, and was assigned to various ZI weather stations where he served as Base Weather Officer. Following separation from the service as a Captain in February 1946, Mr. Sissenwine joined the Office of the Quartermaster General Research and Development Group, serving there as a meteorologist, physicist and climatologist. He was recalled to active duty in August 1951, and served as bioclimatologist to the Korean front-line triservice cold-injury research team. In 1953, Mr. Sissenwine returned to civilian status, joining the Geophysics Research Directorate, AFCRC (predecessor of AFCRL) as Chief and organizer of the Operational Applications Section. This Section was assigned responsibility for all geophysical design problems of the Air Research Development Command (predecessor of AFSC). He has been with AFCRL ever since.

Mr. Sissenwine has been Chief of the Design Climatology Branch, Aerospace Instrumentation Laboratory, since 1963, in which position he has continued his efforts to provide information on atmospheric variability applicable to design problems. He is a professional member of the American Meteorological Society, and a member of the American Geophysical Union and American Association for the Advancement of Science. He has a number of awards and patents to his credit.

Mr. Henry A. Salmela is a research meteorologist with the Design Climatology Branch, Aerospace Instrumentation Laboratory, AFCRL. He attended the University of Mass. and, in 1939, received his B.S. in Physics and Mathematics. He studied meteorology at M.I.T. and received a diploma with the Air Corps class which was graduated in September 1943. After the war, he did graduate work in Experimental Statistics at No. Carolina State College. While employed at AFCRL, he has taken two summer courses at M.I.T. -- one in Applied Climatology and the other in Operations Research.

During World War II, Mr. Salmela was primarily a long-range weather forecaster at Mitchell Field, N.Y. and at MacDill Field, Florida. He later joined the Large Scale Section of the Atmospheric Analysis Laboratory of the Geophysics Research Directorate, AFCRC (predecessor of AFCRL) in August 1949, with the responsibility of conducting a research program directed toward the development of new and improved long-range weather-forecasting methods. This project was terminated in 1957, after which he joined the Stratospheric Forecasting Project where he specialized in climatology studies of upper-air data above 15 kilometers.

Mr. Salmela joined the Design Climatology Branch in 1958. He is now engaged in work on the variability of winds in time and space, errors in observing winds, and in their analyses. He is also doing research on water vapor in the stratosphere and preparing a humidity atlas of the northern hemisphere. He is a member of the American Meteorological Society.

Norman Sissenwine (left) and Henry A. Salmela check plots showing humidity from ground level up to the mesopause at 80 km.

AIR FORCE CAMBRIDGE
RESEARCH LABORATORIES

AFCRL IN 1968 CONTINUES AS NATION'S LARGEST USER OF RESEARCH VEHICLES

In 1968 AFCRL scientists, as they have each year for the past decade, placed more instruments aboard more research vehicles--rockets, balloons, instrumented flying laboratories and satellites--than any other research group in the country. During the past year, AFCRL scientists launched 46 research rockets from sites as far north as Ft. Churchill, Canada, and as far south as Brazil. AFCRL launched 110 research balloons, and its 6 flying laboratories made 374 research flights to all parts of the world. Nine satellite experiments were designed, and 8 of these were successfully placed in orbit.

AFCRL is the Air Force center (one of the major National centers) for research in the environmental sciences--research that includes geology, geodesy, gravity, meteorology, ionospheric phenomena, the chemistry and physics of the upper atmosphere, and solar effects on the earth's environment. The use of large numbers of instrumented vehicles is an intrinsic part of this research.

Instruments aboard the research rockets (Aerobee 150s, NIROs, Javelins, Nike-Tomahawks) designed to make high-precision *in situ* measurements included ultraviolet spectrometers, ion probes, mass spectrometers, and photometers. Other rockets were designed to inject chemicals into the upper atmosphere, and to collect micrometeorites for laboratory analysis. During 1968, AFCRL launched rockets from Ft. Churchill, Canada; the White Sands Missile Range, New Mexico; Eglin AFB, Florida; Wallops Island, Virginia; Puerto Rico; and Brazil. In addition to the 46 research rockets, AFCRL launched 75 smaller meteorological rockets during the year.

Of the 110 large research balloons launched in 1968 at AFCRL's 2 balloon-launch facilities at Holloman AFB, N.M., and Chico, Calif., most had flight durations of 3 to 8 hours, and reached altitudes between 70,000 and 100,000 feet. Typical balloon-borne experiments involved the measurement of atmospheric tidal motions in the stratosphere, infrared spectra of the moon, heavy primary and gamma rays entering the atmosphere, and solar constituents. The most significant flight took place on September 11, 1968 when AFCRL launched the largest balloon ever sent aloft. This balloon had a volume of 28.7 million cubic feet (previous record, 26 million cubic feet), and ascended to the record balloon altitude of 160,200 feet, 10,000 feet higher than the previous balloon record.

AFCRL's 6 flying laboratories--three C-130s, two KC-135s and a C-131--made a total of 374 research flights during the year. These flights ranged over most of the globe. The most significant of these was a circumpolar flight made in December 1968 by one of AFCRL's KC-135 aircraft. This flight provided the first complete measurements of the auroral oval. Equipment aboard included a Granger 3900 ionosounder, a 4-barrel photometer, infrared spectrometers, and an all-sky 35-mm camera. One of the AFCRL C-130 aircraft, instrumented to measure the transmission of optical radiation through the atmosphere, remained 2 months in Thailand collecting data on the propagation of optical radiation in Southeast Asia. Another C-130, equipped for meteorological observations, made 2 extensive tests in the U.S. Southwest during the year as part of a program designed to obtain quantitative data on the effectiveness of cloud-seeding techniques.

The number of AFCRL satellite experiments in 1968 declined from the number conducted in past years. AFCRL scientists designed 9 such experiments to be carried aboard Air Force satellites. Eight of them were successfully orbited and provided good data. The most significant of the AFCRL satellite experiments consisted of a 23-inch-diameter, 600-pound sphere designed to measure atmospheric density. This small, heavy satellite, nicknamed the "Cannonball," had a perigee of only 84 nautical miles, which carried it relatively deep into the earth's atmosphere. Atmospheric density was detected by a triaxial accelerometer, and by changes in orbit due to atmospheric drag.

Projections for 1969 show no marked change in AFCRL's large use of research vehicles to conduct its environmental research program.

helicopter technique for clearing warm fog and clouds

METEOROLOGY
LABORATORY, AFCRL

A simple technique for clearing large openings in cloud and fog layers has been demonstrated in tests conducted by AFCRL scientists. Warm fog layers 200 feet thick were repeatedly cleared using helicopter rotors to force dry air above the fog or cloud layer into the moisture-laden air below. Non-reforming clearnings of almost a mile in diameter were repeatedly made in clouds in about 10 minutes. These encouraging results have been reported following a 3-week series of tests in November 1968 carried out in the vicinity of the Smith Mt. Airport near Roanoke, Virginia.

This is the second series of successful tests of the helicopter technique conducted by AFCRL. In April 1968, the feasibility of the technique was demonstrated in tests over the Gulf of Mexico, near Eglin Air Force Base, Florida. Both the Eglin and the Smith Mt. Airport programs were directed by Vernon G. Plank of AFCRL. Smith Mt. Airport was chosen because it is located in a basin area fed by a constant source of moisture from nearby Smith Mt. Reservoir. These factors combine to produce frequent fog conditions ideally suited for the tests.

These latest results show that fog caused by nighttime radiational cooling, and reaching heights of about 200 feet, can effectively be cleared by helicopter rotors. For optimum effectiveness, twin-engine helicopters with gross weights of about 20,000 pounds are prescribed.

Of the many flight patterns tested, the following procedure seems to bring the best results: the helicopter ascends to an altitude of 500 feet above the cloud or fog deck, where it hovers. The downwash traces a clearly visible circular outline of the area to be opened. The helicopter then descends to the center of the circle 100 feet above the layer. At a speed of about 30 miles an hour, the helicopter flies in an expanding spiral pattern, outward.

The clearing begins within a minute or so of the operation, and continues to expand after the helicopter has completed its operation. The opening is produced because the rotors direct the warm, drier air from aloft into the moist lower layer. In the mixing process, the dew point of the moist layer is raised and the water droplets evaporate.

The clearing rate depends primarily on the gross weight of the helicopter and the lift-load characteristics of its main rotor. Two CH-3E twin-jet Jolly Green Giants were used in last month's tests. The method also requires that the relative humidity of the drier air must be 90 percent or less.

Warm-fog dissipation is far less tractable than the dissipation of supercooled fog or clouds, a fairly common winter occurrence. Supercooled clouds contain droplets in the liquid state at below freezing temperatures. In experiments conducted several years ago, AFCRL demonstrated that large holes in supercooled clouds can be opened by seeding them with dry ice pellets.

The AFCRL-developed technique has already been used at least once in Vietnam operations. Following AFCRL's successful Eglin AFB tests earlier in the year, instructions on the employment of the technique were distributed to operation commanders in Southeast Asia, and a downed pilot was rescued from a ridgeline through a hole in clouds made by two HH-53B (Super Jolly Green Giant) helicopters. The pilot, hidden by a solid cloud layer, was recovered when the helicopters cleared an opening and lowered a rescue line. His rescue was a direct result of AFCRL's clearing technique.

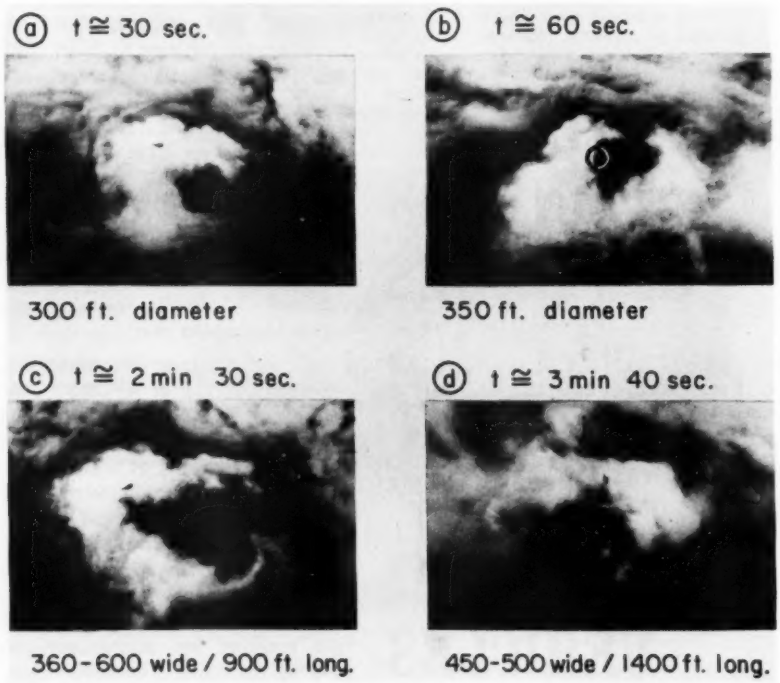

(a) t ≅ 30 sec.
(b) t ≅ 60 sec.
300 ft. diameter
350 ft. diameter
(c) t ≅ 2 min 30 sec.
(d) t ≅ 3 min 40 sec.
360-600 wide / 900 ft. long.
450-500 wide / 1400 ft. long.

Figure 1. Progressive enlargement of hole in cloud as helicopter circles outward above the cloud top.

DASA AND AIR FORCE PLAN EXTENSIVE STUDY OF RADIO BLACKOUT

IONOSPHERIC PHYSICS LABORATORY, AFCRL

AFCRL, the Army Ballistic Research Laboratory, and the Defense Atomic Support Agency (DASA) this summer will jointly conduct an extensive study of the effects of solar disturbances on radio propagation in the Arctic. The program calls for the launch of 36 research rockets (Nike Iroquois, Black Brants, Nike Javelins, and Arcas) within a 36-hour period. The launches will take place immediately after the onset of a polar-cap absorption event (PCA). PCA is a radio-blackout phenomenon peculiar to the Arctic region. The program will be conducted from the Churchill Research Range, Manitoba, Canada.

An extensive support program involving high-altitude aircraft, an orbiting satellite, and ground-based instruments is planned. Two AFCRL KC-135 flying laboratories will be used, one instrumented to measure ionospheric phenomena, the other to measure optical transmissions in the atmosphere. The satellite, instrumented by the Lockheed Corporation, will measure the concentrations and energies of high-energy protons. Ground-based riometers will measure electron densities in the D-region of the ionosphere during a PCA event.

The 36 rockets to be used in the program will reach altitudes of 80 to 150 km. A launch schedule of this magnitude has never before been attempted at any rocket-launch range. The rockets are instrumented for making a variety of measurements. Several rockets are designed to measure the distribution of charged-particle densities, temperatures and energies. Another group is instrumented to measure radio transmission properties. Other rockets will release falling spheres which can be tracked from the ground and which will provide data on atmospheric density. Another group of rockets will carry mass spectrometers to collect data on the composition of the upper atmosphere during the period of solar proton disturbance.

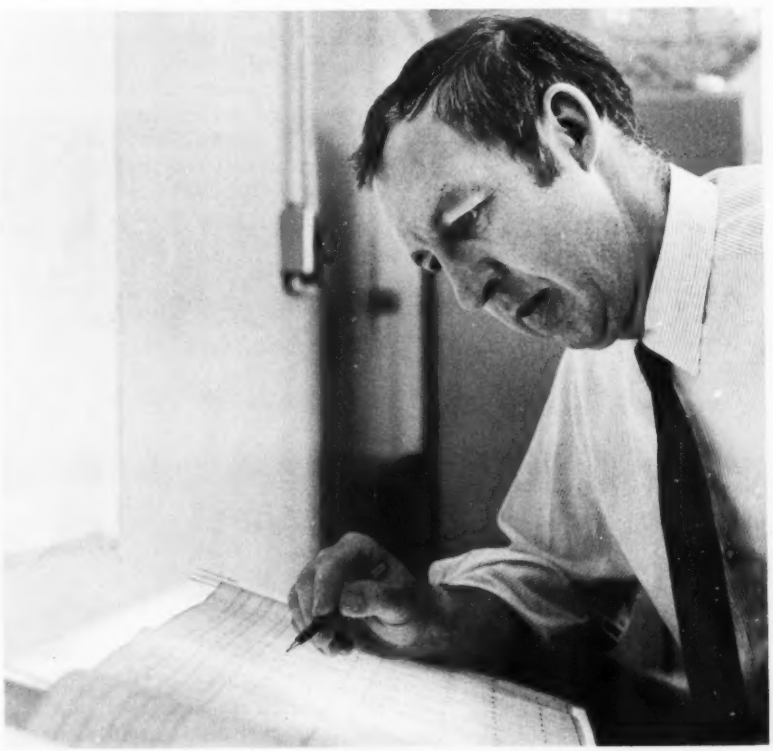
Radio blackout in the Arctic has its origin in the sun. The sun is presently in the active phase of its 11-year sunspot cycle. Closely associated with the large number of sunspots that occur during the active cycle are giant bursts of solar energy--solar flares--that periodically erupt from the sun. The dense flux of charged particles and X rays released by these flares can have pronounced effects on the earth's environment.

One of these effects is the aurora. But the most serious, from the standpoint of military operations, is radio blackout over large regions of the Arctic. This blackout--or PCA--results directly from high-energy protons entering the atmosphere along magnetic-field lines in the Arctic. Increases in ionospheric density resulting from solar activity can extend far beyond the Arctic to affect electronic systems designed for communications, navigation and radar detection on a global scale.

The objective of the test program is to uncover clues for predicting the onset, intensity, and duration of PCA events. James C. Ulwick of AFCRL is the Technical Director of the Program.

Mr. James C. Ulwick is a research physicist with the Ionospheric Structure Branch, Ionospheric Physics Laboratory, AFCRL. He attended Tufts University, Medford, Mass., and in 1950 received his B.S. in Physics. He also attended Tufts University Graduate School in 1950 and 1951, and the University of Maryland Graduate School in 1951 and 1952. From 1952 to 1953, he was with the Naval Research Laboratory, Washington, D.C., working on long-range navigation systems.

Currently, Mr. Ulwick is conducting rocket research of the ionosphere, with emphasis on the physical chemistry of disturbed polar ionospheres. He is Project Officer for the Defense Atomic Support Agency, and has several publications to his credit.



OPTICAL PHYSICS LABORATORY, AFCRL

ATMOSPHERIC VISIBILITY IN SOUTHEAST ASIA

Just how well infrared and other optical instruments used for guidance, surveillance, reconnaissance and target acquisition perform often depends on the atmospheric conditions at a specific time and place. In Vietnam, for example, atmospheric transmission properties are not the same during the dry season as they are during the monsoon season. The visibility properties of terrain features also differ during the wet and dry seasons.

For these reasons, on 14 February 1969, AFCRL's C-130A flying optical laboratory began a 10-week series of optical measurements over Thailand during the dry season. The program is designated Phase II. Phase I was conducted in the same area during the monsoon season in September and October 1968.

Participating in the program are 16 scientists and engineers from AFCRL and the Scripps Institution of Oceanography, under the project direction of Major Leo J. Sheehan of AFCRL. Dr. Robert W. Fenn of AFCRL is program director. The C-130A flying laboratory will operate out of the U-Tapao Air Field. Instruments aboard the aircraft will observe the same typical geographical areas that were observed during the earlier series, i.e., areas selected for their distinct terrain features. These are the Khorat Plateau, a region of forest and relatively high elevation; Lop Buri, with its rice paddies and delta region features; the Rayong area, with its typically heterogenous vegetation on the southeast coast of Thailand; and the Chumphon area, with its mountainous seacoast, along the Isthmus of Kra.

Instruments aboard the aircraft include 12 optical and several meteorological subsystems, all mated to a high-speed data-recording system. In addition to the airborne system, a complementary mobile ground station is used, operated with support from the Thais. The ground station serves as a control for the data collected by the aircraft, and has a duplicate set of instruments. These instruments will observe targets at close range without the background interference of the atmosphere. Differences in target resolution between the airborne instruments and ground-based instruments can be attributed to atmospheric masking. In addition, the ground station will collect general meteorological synoptic data on a continuous basis. The airborne and ground instrumentations were fabricated and installed at a cost of about one million dollars. The instrumentation program, completed in July 1968, greatly expanded the state-of-the-art in photometry and aerosol-measurement techniques.

The earlier Phase-I operation, which also lasted 10 weeks, was highly successful. Previously lacking, and of particular value, were optical data for a tropical nighttime environment. Similar low-light level measurements over a range of altitude levels will be made during the forthcoming series. The data gathered during both series of measurements will undergo computer analysis, the purpose of which is to establish prediction criteria for the performance of optical sensors in a given environment. Essentially, AFCRL is seeking an answer to the question: "What will be the level of contrast between a particular target and its background as a function of sensor frequency, altitude and atmospheric condition?"

Major Leo J. Sheehan is Project Officer with the Atmospheric Optics Branch, Optical Physics Laboratory, AFCRL. He attended the U.S. Naval Academy, and in 1956 received a B.S. in Military Sciences. In 1962 he received his M.S. in Electrical Engineering from the University of Illinois.

Major Sheehan has been a Missile Combat Launch Team Commander and an Assistant Operations Officer. In recent years he has also been a project scientist in the field of electromagnetic wave propagation. After completing a year's study on the Management of Research with the Air Force Institute of Technology, he became Project Officer of the Atmospheric Optics aircraft measurements program. He will be investigating the optical properties of the atmosphere in various parts of the world.

Major Sheehan was awarded the Air Force Commendation ribbon for his work in electromagnetic propagation. In addition, in 1968, he received a $500 award for Outstanding Scientific Achievement in Research.

Figure 1. C-130 aircraft used in the atmospheric visibility studies in Thailand.

Fourier Spectroscopy in Real Time

OPTICAL PHYSICS LABORATORY, AFCRL

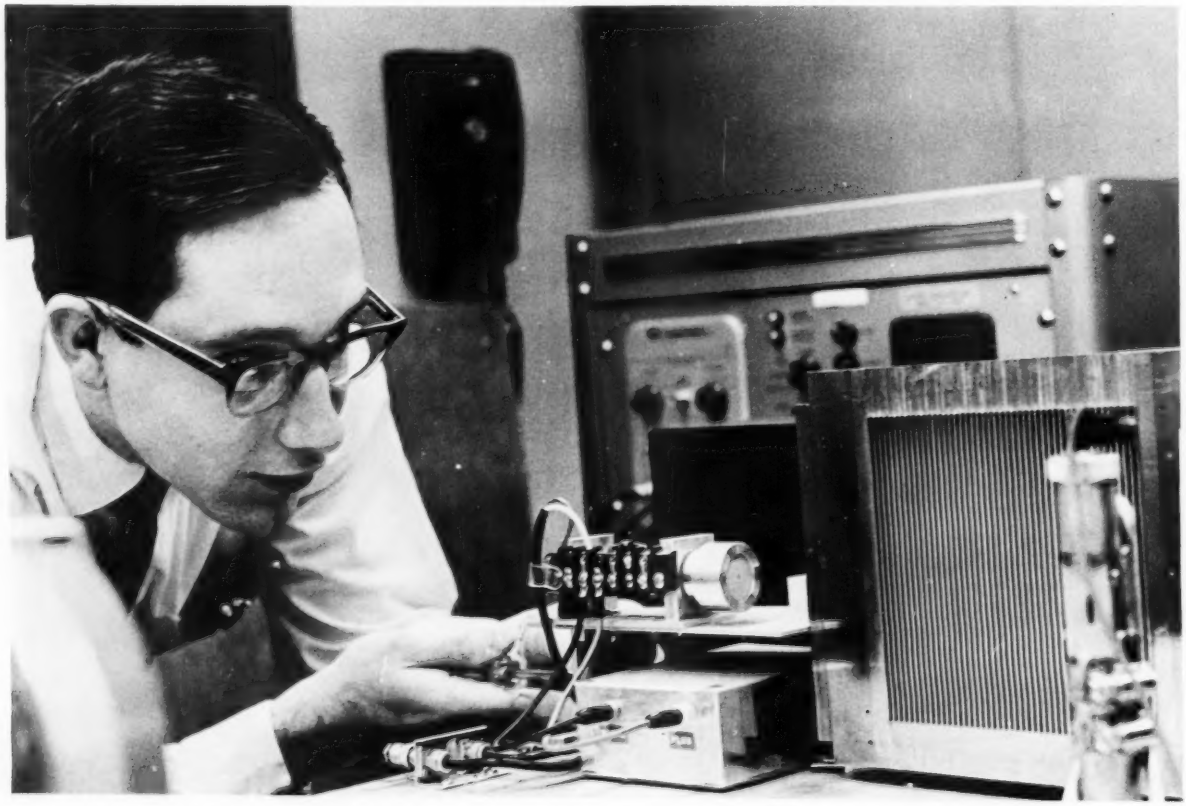
Here is a truism that we all learned long ago, but which needs to be restated periodically to refresh our perspective: no instrument is more important to research than the spectrometer, and no field of study has taught us more about the nature and structure of matter than infrared spectroscopy. Since infrared radiation was first dispersed into a spectrum in 1890, countless advances in the art of spectroscopy have been made.

A most recent advance is described by Dr. Joseph E. Hoffman, Jr., of AFCRL, in his report, "A System to Perform Real-Time Fourier Spectroscopy" (AFCRL-68-0401). Fourier spectroscopy itself is fairly new, dating back only about 10 years; and AFCRL, with a special contribution by Dr. George A. Vanasse, has done much to bring Fourier spectroscopy to its present state.

The term, Fourier spectroscopy, may be misleading because the product of Fourier spectroscopy is nothing more than a continuum-type of spectrum similar to what we get from a conventional infrared spectrometer. The Fourier spectrum is obtained indirectly, by synthesis, and is reconstructed from an interferogram. The interferogram is produced by a simple Michelson interferometer which splits an incoming wave front into two beams and introduces a delay into the path of one of them. The beams are then recombined to produce the interference patterns, known as interferograms.

The interferogram, by itself, isn't very instructive. It doesn't tell one much about the rotational, vibrational and electronic energy levels of sample molecules--or the internuclear distances, force constants, dissociation energies and all the rest, which is the kind of information the infrared spectroscopist is really looking for. To learn these things, one must perform a Fourier transform on the interferogram.

The interferogram-Fourier transform route to an infrared spectrum has two advantages. First, the interferometer, compared to the conventional spectrometer, views a source with a much larger aperture, and thus allows more energy to reach the detector. Next, the interferometer has what is called the "multiplex" advantage, which gives an improved signal-to-noise ratio. These advantages, particularly in the far-infrared where sources are weak and detectors are insensitive, lend great attraction to Fourier spectroscopy.



Dr. Joseph Hoffman aligns spectrographic equipment for a Fourier transform spectroscopy experiment.

These advantages are so attractive that it becomes quite worthwhile--even essential--to devote many many hours of computer time to perform the necessary Fourier transformations on the interferogram. To obtain a spectrum often takes hours and fairly sizeable computers.

This, then, is the present state of things. Dr. Hoffman, however, has carried Fourier spectroscopy a step further. The system that he has worked out theoretically and has tested experimentally is one that can display Fourier synthesized spectra on an oscilloscope immediately after the sample is observed. His system for performing real-time Fourier spectroscopy is one that substitutes a highly specialized spectrum synthesizer for the computer. His entire system is small enough for easy transport to remote field sites, or for use aboard aircraft. It can also be designed in a package small enough to be carried aboard balloons or satellites.

Dr. Hoffman devotes a considerable portion of his report to the principles of operation of the spectrum synthesizer. Here are a few clues as to what is involved: only selected points on the interferogram are sampled, and these sample points are located at equal increments of path difference. The spectrum is synthesized by the successive summation of a series of harmonic functions (cosines) whose amplitudes are controlled by the value of the interferogram at the sample points, and whose frequencies are related to the path difference at the same sample points. Since an additional cosine function is added to the spectrum synthesis each time a sample is taken, the final spectrum is ready for study as soon as the interferogram has been taken. Thus, the system operates in real time.

The real-time advantage is best illustrated in the relative times it took a special-purpose analog computer, a digital computer, and Hoffman's system to obtain a spectrum from a particularly complex set of data. The problem required 16 hours for the analog computer, almost a day for the digital computer, and 8 minutes for Dr. Hoffman's system, with the 8 minutes being the time required to produce the interferogram.

This comparison may not be fully justified, because the computer has the advantage of greater precision. For many applications, however, this advantage is greatly offset by the speed of operation, small size, cost, and portability.

Dr. Joseph E. Hoffman, Jr., is an electronics engineer with the Infrared Physics Branch, Optical Physics Laboratory, AFCRL. He attended Rensselaer Polytechnic Institute, and in 1957 received the B.E.E. degree in Electrical Engineering. In 1959, he received his M.S. E.E. in Electrical Engineering from the University of Pennsylvania, and his Ph.D. in Electrical Engineering from Northeastern University in 1968.

Dr. Hoffman was formerly employed by Utah State University from 1963 to 1966. Previous to that he worked for AFCRL from 1959 to 1963. The first three years of this period were spent as an officer in the USAF. Prior to that, from 1957 to 1959, he was employed by the Radio Corporation of America.

Currently, Dr. Hoffman is investigating real-time techniques to obtain spectral data from interferograms and the electronic design of control and data-acquisition systems for a high-resolution interferometer. He is a member of the Institute of Electronic and Electrical Engineers and the New Jersey Society of Professional Engineers. He has several papers to his credit.

does geodesy require an improved value for the velocity of light?

TERRESTRIAL SCIENCES LABORATORY, AFCRL

Satellites have revolutionized the science of geodesy--the measuring of distances between two distant points on earth, and the size and shape of the earth. During the past decade, some 20 or so satellites have been used for geodetic measurements--satellites with flashing lights, satellites with radio beacons, satellites carrying reflectors for returning laser signals, and huge spherical satellite balloons.

Using satellites, we have improved the accuracy of long-distance geodetic measurements by an order of magnitude. A realizable present goal is an accuracy of 1.5 meters over a distance of about 1500 km. The radius of the earth may soon be known to an accuracy of approximately 6.5 meters. We have now just about reached the limits of the accuracy that can be obtained with our present state-of-the-art.

The most critical value in satellite geodesy is the value for the velocity of light. Owen W. Williams, Director of AFCRL's Terrestrial Sciences Laboratory, has recently examined this parameter in a paper entitled, "Does Geodesy Require an Improved Value for the Velocity of Light?" His answer is "No." In arriving at the answer, he provides some interesting and illuminating features on modern geodesy. He concludes that, although we would like to have a more accurate value for the speed of light, the geodesist is presently faced with other sources of error which are greater. Until we resolve other error sources, geodesists cannot take full advantage of an improved value of the velocity of light.

Because c, the velocity of light, is one of the great constants of the universe, we (including physicists, who really should know better) tend to assume that the velocity of light is known with absolute precision. And of course it isn't. As late as 1941, the weighted mean of all the values was used to arrive at an accepted value of 299,776 km per second. This value turned out to be about 16 km/s too low. The presently accepted value for

the speed of light recommended by the Committee on Fundamental Constants of the National Academy of Sciences-National Research Council in 1963 is 299,792.5--plus or minus 0.3 km/s. This value has an accuracy of 1 part in 10^6. (As a matter of historical interest, Williams notes that the first person to conclude that light has a finite velocity was a Danish astronomer, Ole Romer, who observed a short delay in the period of the closest approach of Jupiter to earth and the eclipse of Jupiter by the earth.)

Williams examines the primary errors involved in high-precision distance measurements using radio or light signals. There are three classes of these--instrumental, atmospheric effects, and the speed of light in a vacuum.

Instrumentation errors include such considerations as modulation distortion impressed on the radiation, drift in the electronics, and many others. The last 10 years have seen a tremendous advance in the state-of-the-art of electronics, and instrumentation errors are now so minimized that the precision of instrumentation is well within 1 part in 10^6--matching the accuracy to which the velocity of light is known.

The most critical of the errors are the atmospheric effects of electromagnetic radiation. Temperature, pressure, and humidity all affect the velocity of propagation. This major uncertainty can be resolved only if we can obtain information at every finite point along the observed path--and this is clearly impossible. The uncertainty resulting from atmospheric inhomogeneities is at present several parts in 10^6.

With respect to the velocity of light, Williams considers several methods well within the state-of-the-art which could improve the present 1 part in 10^6 accuracy to a value which would be accurate to 1 part in 10^8--at least for baseline distances up to 1 mile. He predicts that, within the next 5 years, such accuracies will be realized.

It is from these considerations that Williams concludes that geodesy does not at present require an improved value for the speed of light. Other error sources are presently larger. He speculates that, even after all the present error sources are corrected, "--we wouldn't be surprised if something like earth micromovement will turn out to be the most serious restraint we face in geodetic measurement."

Mr. Owen W. Williams, a physical scientist, is presently the Director of the Terrestrial Sciences Laboratory, AFCRL. He received his A.B. degree with honors from Kalamazoo College in 1948. From 1948-1950, he attended the George Washington University Graduate School, and subsequently took courses in geophysics and management at universities in the Boston area.

After military service with the Navy in the Pacific Theatre during World War II, Mr. Williams joined the Army Map Service, Washington, D.C., and served there as a geodesist from 1948-1955. From 1955-1957, he was with the Geoscience Branch, Aeronautical Chart and Information Center, as Assistant Chief and then Chief. He has been with AFCRL from July 1957 up to present time.

In addition to directing and managing research efforts in the field of terrestrial sciences, Mr. Williams has more recently been engaged in work on laser and satellite geodesy. Many of his innovations have been formulated into new techniques and approaches to the general problem of obtaining more precise data on the size and shape of the earth. He has authored over 40 scientific and technical papers in recent years on the subjects of geodesy and gravity. He is a member of the Earth Science Technologies Association; the Cambridge Research Chapter, Armed Forces Management Association; the American Geophysical Union; the International Union of Geodesy and Geophysics; the Instrument Society of America; the American Association for the Advancement of Science; and the New England Chapter, American Institute of Aeronautics and Astronautics.

Owen W. Williams, Director of AFCRL's Terrestrial Sciences Laboratory, was one of the pioneers in the field of satellite geodesy.

a high-Reynolds-number hypersonic test facility

CAPTAIN ERIC G. FRIBERG
Fluid Dynamics Facilities Research
Laboratory, ARL

The Air Force research and development program is continually seeking aerodynamic design data on advanced aerospace systems. To do this economically, advanced ground-test facilities are required. The Fluid Dynamics Facilities Research Laboratory, ARL, is trying to advance this state-of-the-art in facilities design. A problem that has become of increasing importance to the Air Force in recent years has been the production of high Reynolds numbers at hypersonic Mach numbers. Because of their size and flight altitudes, maneuverable re-entry vehicles will have turbulent boundary layers which influence heat-transfer and aerodynamic characteristics. A high-Reynolds-number facility most closely simulates the boundary-layer conditions that these vehicles will experience.

Production of a high-Reynolds-number, high-Mach-number test gas suitable for the aerodynamic research required on advanced vehicles is not easy. While high-Reynolds-number flows may be obtained with shock tunnels, the test time is too short to permit detailed boundary-layer investigations. To achieve a long-duration, high-Reynolds-number flow at hypersonic Mach numbers such as 10 to 12, would require a facility of tremendous physical dimensions and enormous development costs if conventional test-facility techniques were applied. Clearly, a new approach to the problem must be devised.

In recent years the Fluid Dynamics Facilities Research Laboratory, ARL, has been studying a novel concept in high-Reynolds-number facilities under contract with Dr. Antonio Ferri and Dr. Victor Zakkay at New York University (NYU). The theoretical basis for this work was outlined in Reference 1. This facility achieves high-Reynolds-number conditions with flow times on the order of seconds by using extreme pressures in a mechanically unique fashion. It is no larger than conventional facilities,

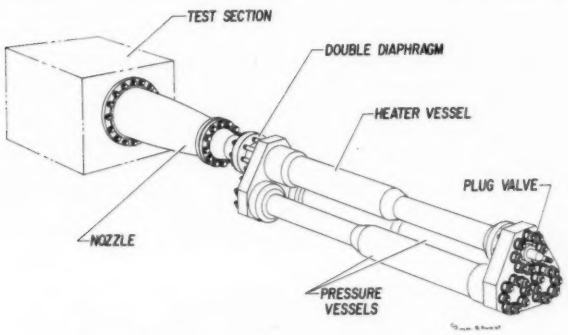


Figure 1. High-Reynolds-Number Hypersonic Facility.

and considerably less costly than other high-Reynolds-number techniques. The facility is now operational and excellent test results have been obtained.

The NYU high-Reynolds-number facility (Figure 1) consists of 3 large steel tubes, 2 of which are connected to feed the 3rd. The upper tube, containing the air heater, is directly connected to the hypersonic nozzle and test section. Tubes are pressurized to some initial pressure. The electric air heater then raises the temperature above condensation limits, and this constant volume heating also raises the pressure. Figure 2 shows typical test results where the pressure was raised from 9,000 psi to 18,400 psi, and the temperature from 500°R to about 1,800°R. Flow is

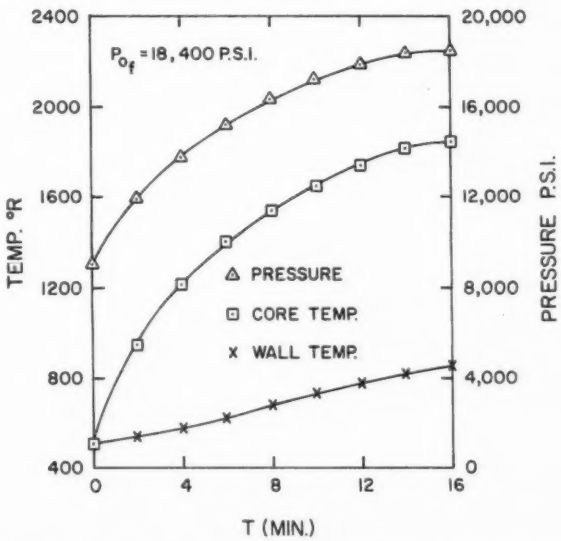


Figure 2. Pressure and temperature increase due to constant volume heating.

initiated by bursting diaphragms, and a useful test time of approximately 4 seconds is obtained. Typical pressure and temperature traces from the facility are shown in Figure 3 along with a sample Mach-number calibration. Reynolds numbers like 2×10^7/ft can now be produced at hypersonic Mach numbers with flow times sufficient for boundary-layer research. Additional calibration results, as well as a complete description of the test facility, are available in Reference 2.

The NYU high-Reynolds-number facility sponsored by ARL has proved a new concept in the design of ground-test facilities. Great interest in this test technique has been expressed by NASA and the U.S. Navy. The operational status of this versatile facility gives the Air Force a significantly new capability for testing at high Reynolds

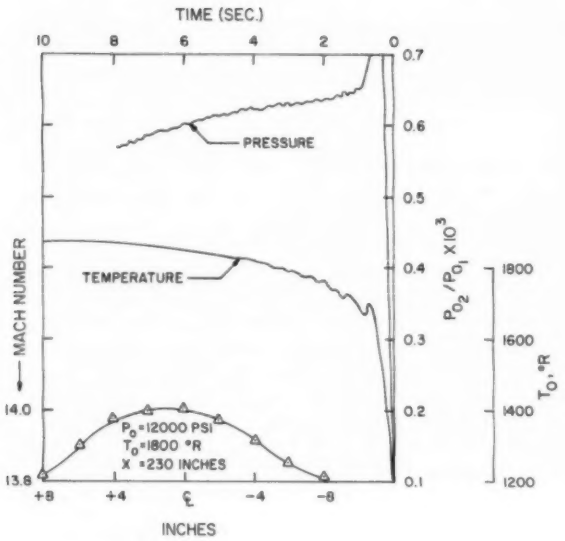


Figure 3. Stagnation pressure and temperature traces from the high-Reynolds-number hypersonic facility. In the lower portion of the figure is a typical jet Mach-number distribution.

number and hypersonic conditions, and at relatively low cost.

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Captain Eric G. Friberg was formerly assigned to the Fluid Dynamics Facilities Research Laboratory, ARL. As project engineer on the Mach-14 hypersonic wind tunnel, his primary responsibilities were to assure the operation of, and aid testing in, this facility. In line with the stated mission of the Laboratory, Captain Friberg had under his direction several projects related to facilities research.

The son of a foreign service officer, Captain Friberg attended schools both here and in Finland, Sweden, and Germany before entering Harvard University. After being graduated from Harvard in 1964 with an A.B. in Engineering and Applied Physics, he went directly to graduate school at MIT where he obtained his M.S. in Aeronautics and Astronautics in 1965.

Captain Friberg received his commission through the AFROTC program in June 1964, took an educational delay to obtain his master's degree and was assigned to ARL from September 1965 until just recently. He left the service just a short while ago, and is now with private industry.

measurement of the earth's electric field

SPACE PHYSICS LABORATORY, AFCRL

Geophysicists assume that the earth has an electric field as well as a magnetic field. But no one has measured it directly. Two AFCRL scientists--Ludwig Katz and Captain Paul L. Rothwell--in a paper appearing in the December 23, 1968 *Physical Review Letters* have reported strong indirect evidence of the earth's electric field in the polar regions. The evidence was gathered by a satellite designed to measure the energies, intensities, and angular distributions of charged particles.

Evidence for the electric field was obtained by the Air Force satellite OV1-9 which, during a period of high solar and magnetic activity in late May 1967, detected a concentrated stream of protons flowing upward from the

atmosphere outward into space. The upward-moving protons were traveling at more than 50,000 miles per second. (NASA's Explorer 31 has also observed upward-moving protons, but at an altitude considerably higher than the protons observed by the OV1-9.)

By calculating the energy of these protons and their velocity relative to the earth's magnetic field lines, the AFCRL scientists were able to deduce the existence of an electric field and calculate its average strength. The calculations--as well as the assumption that an electric field exists in the first place--are based on certain concepts of hydromagnetics. When you have a conducting medium (in this case, the charged particles in the ionosphere and in the radiation belts) moving in the presence of a magnetic field, an electric field is produced. Changes in any one of three basic parameters--magnetic field, electric field, and the velocity of a conducting medium--induce changes in each of the others.

It is possible to measure the earth's magnetic field directly with magnetometers (or a compass for that matter), and to measure charged particles with a variety of detectors; but there are no instruments available that can directly measure the earth's electric field. The field is too weak to overcome the "noise" of competing fields created by the measuring instruments themselves. Until this problem is overcome, it is unlikely that we shall ever be able to plot the structure of the earth's electric field on a map as we now plot lines of equal magnetic intensity.

The OV1-9 satellite, which first detected the upward-moving protons, had an apogee of 4,800 km when it was over the magnetic North Pole. The spin of the satellite was such that a proton detector on board was able to scan almost all pitch angles. (The pitch angle is the angle relative to the magnetic-field line.) On three separate orbits, during a period of high solar and magnetic activity, a highly collimated flux of protons was detected coming up the field lines from the earth at magnetic latitudes above 70 degrees. The proton detector had 5 energy channels that allowed the measurement of energies at intervals between 240 and 1,000 keV. In addition, a 0.200-gauss magnetometer was carried aboard the satellite to determine the instrument's orientation relative to the magnetic field.

Before the two AFCRL scientists concluded that the protons had, in fact, emanated from some point in the earth's ionosphere and were not due to other effects (scattering effects, or the mirroring of protons in the radiation belts in which protons bounce back and forth from hemisphere to hemisphere along magnetic field lines), careful calculations of angular distributions and energies were made. The two scientists concluded that the angular distributions and energies observed were most readily explainable by the presence of a radial polar electric field. The average strength of the electric field was calculated to be 0.14 volt per meter.

Although the existence of the electric field is indicated in the study, its structure is still unknown. The AFCRL scientists suggest a complex structure that extends far out into space.

Mr. Ludwig Katz is Chief of the Cosmic Radiation Branch, Space Physics Laboratory, AFCRL. He attended the Wilhelms Gymnasium in Kassel, Germany and later, after immigrating into the USA in 1938, attended Temple University from which he received the degree of Bachelor of Arts with Distinction in Physics in 1945, and the Master of Arts degree in 1947.

Mr. Katz received a teaching fellowship in Physics at the Massachusetts Institute of Technology, where he remained for two years. He has been with AFCRL since 1950.

At the present time, as Chief of the Cosmic Radiation Branch, Mr. Katz conducts theoretical and observational research on the radiation environment of our planet. The current emphasis of the work is on conceiving and implementing techniques to measure radiation in nearby space, and to understand the plasma interactions possible within the earth-sun system which permit anomalous radiation conditions to arise.

Mr. Katz has a number of publications to his credit, and is a member of the American Physical Society, the American Geophysical Union, RESA, and Pi Mu Epsilon.

Captain Paul L. Rothwell is a physicist with the Cosmic Radiation Branch, Space Physics Laboratory, AFCRL. In 1960 he was graduated from Harvard College with an A.B. degree in Engineering and Applied Physics. He subsequently received M.S. (1962) and Ph.D. (1967) degrees in Physics from Northeastern University.

Captain Rothwell has taught sophomore laboratory sessions for two years, and has worked in both the theoretical and experimental aspects of high-energy particle physics for five years. He is currently analyzing data from the OV1-9 satellite. He has several publications to his credit.

Ludwig Katz (left) and Capt. Paul Rothwell examine data from a satellite-borne cosmic-ray sensor.

conservation laws in general relativity

DR. LOUIS A. TAMBURINO, General Physics Research Laboratory, ARL

The definitions of energy and momentum have marred the beauty of Einstein's general theory of relativity for over 50 years. The difficulties stem from the arbitrary co-ordinate transformations allowed in this theory. Einstein interpreted the components of the space-time metric of a curved Riemannian space as the potentials of the gravitational field. This is formulated in his Principle of Equivalence which states that the gravitational mass is equivalent to inertial mass. This implies that gravitational effects can be eliminated "locally" by a co-ordinate transformation; in other words, the metric can be transformed "locally" into a form identical to the Minkowski metric of special relativity. In order to do this, one must allow co-ordinate transformations that depend on four arbitrary functions. I shall contrast the general theory of relativity with the special theory in which satisfactory definitions of energy and momentum can be formulated. Gravitational forces are extremely weak compared with electromagnetic and nuclear interactions, and are usually neglected in the special theory. There, one uses a unique form of the space-time metric that does not include a description of gravitation.

Most dynamical equations are derivable from a Lagrangian through a variational principle. A group of transformations which leaves the Lagrangian invariant necessarily leaves the dynamical equations of the system unchanged. In special relativity, Lagrangians are Lorentz invariant and, in general relativity, the Lagrangian must remain invariant under an arbitrary co-ordinate transformation. There is an important theorem by Noether which states that, if a Lagrangian is invariant under an N parameter transformation group, then there are N well-defined conservation laws. The Lorentz group is a 10-parameter group and leads to 10 conservation laws of energy, momentum, and angular momentum.

The transformation group in general relativity depends on four arbitrary functions which are equivalent to an infinite number of one-parameter groups. One can appreciate the difficulty in singling out a selected number of these one-parameter groups with which to associate energy and momentum. An infinitesimal co-ordinate transformation is described by a vector field, or by descriptors, ξ^μ, according to $X^\mu{}' = X^\mu + \xi^\mu$. Bergmann and Komar have shown explicitly how to express the conserved quantities in terms of volume integrals over finite or infinite volumes, or in terms of equivalent surface integrals. The problem is finding a privileged descriptor field, ξ^μ, with some physical or geometrical significance.

A certain class of spaces allows transformations which preserve the form of the space-time metric. The descriptors associated with this class are called Killing vectors or fields. In special relativity there are 10 Killing vectors. If a field under consideration is time-independent, one is fortunate to have a time-like, or global, Killing vector, and thus, a definition of energy.

Unfortunately, in most cases of interest, the space does not have global Killing vectors, e.g., radiating fields. Attempts at achieving local definitions of energy have had very limited success.(1) At infinite distances from a static source, the space should become flat in the absence of strong gravitational fields. One can obtain a satisfactory definition of the total energy and momentum in the universe by using the asymptotic descriptors in the surface integrals evaluated at infinity.

More recently, boundary conditions have been generalized to include special types of radiating systems.(2) There are two distinct ways of taking asymptotic limits: along space-like directions, or along light-like rays. The latter approach has been the method which has recently received the most attention, and is the one we shall discuss in the remainder of this article. Light-like, or null, surfaces are generally used as co-ordinate surfaces. This approach has the advantage of giving a more nearly complete geometrical description of the infinite region designated as J^+.(3) The plus sign indicates that we are speaking only of outgoing null directions. Bondi and others, by using this formalism, were able to relate gravitational radiation to a monotonically decreasing mass aspect. Mass is also an elusive concept for complicated gravitational fields. One surprising discovery about J^+ is that the invariance group discovered by Bondi-Metzner-Sachs is larger than the Lorentz group, which was the group one might expect to find.

The relevant property of this invariance group to our discussion is that it contains a unique four-dimensional normal translation subgroup– that is, four unique asymptotic descriptors essential for defining the total energy and momentum in the universe. At ARL, by employing these descriptor fields, Dr. Winicour and the author have sought to formulate a definition of energy and momentum in finite regions. We have found a unique way of propagating the descriptor fields from J^+ along null directions that established preferred descriptors at finite distances from a bounded source.(4)

This procedure assumes that one is given a two-dimensional closed sphere-like surface; the procedure propagates enough information about the descriptor fields to evaluate the surface integrals associated with energy and momentum. However, the conservation law we derived does not associate the energy with a unique volume; in a four-dimensional space-

time diagram, a two-dimensional surface does not define a privileged volume element because of allowed transformations in time.

To visualize this, suppress one space-like dimension and represent the spherical surface by a ring in the xy plane; the third axis is now the time axis. The area inside the ring represents the volume element enclosed by the sphere. Now, in the theory of general relativity, we can warp our xy plane with a co-ordinate transformation involving time, thus changing the surface enclosed by the ring as would a distorted soap film spanned by the ring. Since there is no preferred volume element in the four-dimensional geometry of the theory, we employed the concept of having the energy link the spherical surface in time (the four-dimensional analog) to a group of trajectories passing through a ring. Our surface integrals, which we called energy (momentum) linkages, satisfy the following conservation law: the difference between the energy (momentum) linkages through a closed surface and another closed surface which is taken at a later time is equal to an energy (momentum) flux integrated over any three-dimensional time-like (cylindrical topology) hypersurfaces connecting the closed surface. In order to visualize the different time-like hypersurfaces, one can imagine any cylindical surface connecting two different rings in the reduced dimensional example discussed above.

We have shown that our conservation law is consistent with previous results using null co-ordinate systems, and that our energy momentum linkages transform for different choices of asymptotic descriptors in a linear manner similar to a Lorentz four-vector.

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Dr. Louis A. Tamburino, a research physicist, has been with the General Physics Laboratory, ARL, since August 1964. In his present work, he is concerned with the solutions to the Einstein gravitational field equations and with the interpretation of their possible physical significance with respect to classical and quantum theories of gravitation. In particular, he is studying the definitions of gravitational radiation and the conservation laws of energy and momentum. Dr. Tamburino has completed with Dr. J. H. Winicour, also of ARL, a study of a new version of the initial value problems. This study has correlated many separate but related investigations in this area, and has also resulted in new and unique definitions of energy and momentum.

Dr. Tamburino was graduated from the Carnegie Institute of Technology in June 1957 with a B.S. degree in Physics and a commission in the U.S. Army. During his graduate studies at the University of Pittsburgh, from September 1957 to July 1962, he was a graduate teaching and research assistant in the University's Physics Department.

Dr. Tamburino is a member of the American Physical Society and Sigma Xi, and has several publications to his credit.

measurements of galvanomagnetic effects on single-crystal thin films

DR. VELIO A. MARSOCCI, Department of Electrical Sciences
State University of New York at Stony Brook

The growing importance of thin films in such varied applications as computer memories and logic networks, integrated electronic components, and sensing elements for biological instrumentation has given considerable impetus to the interest in research on conduction phenomena in thin-film structures. The various theories concerning the electrical and thermal conduction properties in the films, as well as the validity of the models for the conduction mechanisms upon which such theories are based, can be tested by reference to the measurements of the galvanomagnetic effects, such as magnetoresistance and the Hall effect, exhibited by the thin films. The investigation of the galvanomagnetic effects is also important from the viewpoint that these effects provide characteristics which, in themselves, may result in a possible approach toward new types of device applications. It is the aforementioned research, sponsored by the Solid State Sciences Division, AFOSR, which is the concern of a large portion of the activity in the Electronics Laboratory in the Department of Electrical Sciences at the State University of New York at Stony Brook, Long Island, N.Y. This work, which to date has been primarily concerned with single-crystal ferromagnetic thin films, also includes measurements on nonferromagnetic materials and on possible device applications.

The relationship between the theories devised for an explanation of electrical conductivity in ferromagnetic single-crystal specimens and the anisotropies observed in measurements of the magnetoresistivity and of the Hall effect in such specimens, involves the influence of the spin-orbit coupling on the conduction processes. The various models which have been suggested may be divided into essentially two main categories. These two

models would indicate that the magnetoresistivity effects may be approached from the viewpoint of anisotropy either in the velocity of the d-electrons or in the scattering processes associated with the s-electrons. In the former case the model (1) is based upon the spin-orbit coupling of the d-shell electrons, whereas the latter model (2), (3) and (4) considers the influence of the spin-orbit coupling on the s-d scattering of the electrons. The present investigations have attempted to resolve the criticisms which have been made concerning the two models and the discrepancies which would appear to separate the two. The results show that both models can be used to explain the anisotropies observed in the magnetoresistivity and, also, that both models give results which are consistent with the results predicted by phenomenological equations derived solely from arguments of symmetry. (5) Additional experimental work is presently being pursued which involves the influence, on these anisotropies, of the presence of nonferromagnetic impurities such as copper, manganese and chromium in the thin films; experiments concerning the planar Hall effect (6) have also been performed and would seem to confirm the anisotropy data obtained from the magnetoresistance measurements.

A different but related phase of the research involves an experimental analysis of an extension (7) of Sondheimer's work which describes (8) the relationship between the Hall effect and the conductivity in thin metallic films. The analysis has shown (8) that previous conjectures, concerning the sensitivity of the results to the electronic bulk mean free path in the material, cannot be considered as conclusive. The analysis is being extended further to include the relationship between the effect of surface scattering and the method of measurement.

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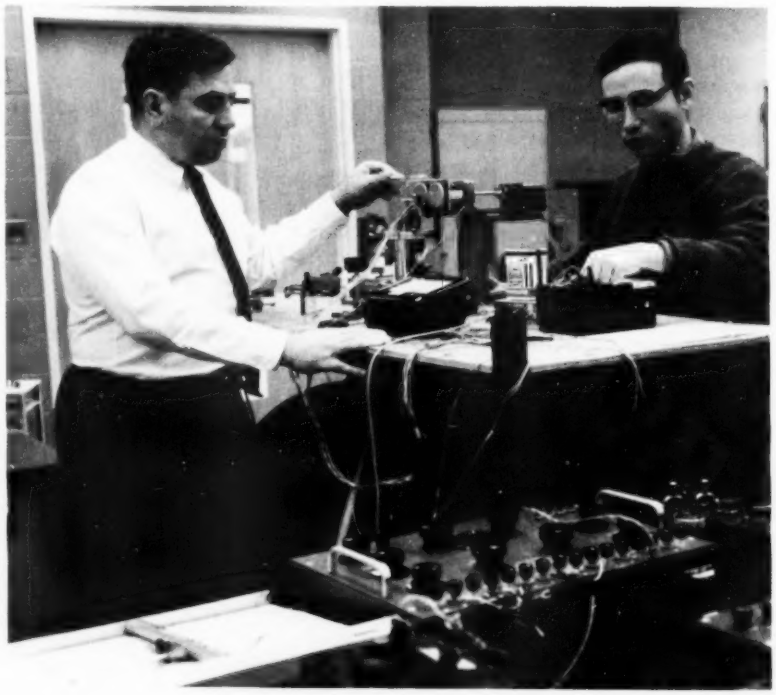
Dr. Velio A. Marsocci is a Professor of Engineering at the State University of New York at Stony Brook, Long Island, N.Y., where he instituted the Physical Electronics Laboratory facility in the Electrical Sciences Department. He served, from 1954 to 1956, as an instructor in the Electrical Engineering Department at New York University. In 1956, Dr. Marsocci received an appointment at the Stevens Institute of Technology, serving as Assistant Professor and then Associate Professor of Electrical Engineering until 1965. He then joined the faculty at the State University at Stony Brook. His teaching and research are primarily in the field of solid-state electronics.

Dr. Marsocci is a member of the American Institute of Electrical and Electronics Engineers, the American Society for Engineering Education, the American Physical Society, the American Association for the Advancement of Science, and the American Association of University Professors. He is also an associate member of the American Institute of Aeronautics and Astronautics, and holds membership in Tau Beta Pi, Eta Kappa Nu and Sigma Xi. In addition, he is a registered Professional Engineer in New York and New Jersey.

Dr. Marsocci is the author of approximately 35 technical papers in the literature of engineering and physics, and has contributed to the Handbook of the Engineering Sciences.



Dr. Velio Marsocci (left) is shown with one of his graduate students, Mr. Thomas Chen, making adjustments on an experimental magnet facility used for low-temperature galvanomagnetic measurements.

recent launchings carry OAR experiments

Four Air Force satellites launched aboard an Atlas F booster on 18 March 1969 from Vandenberg Air Force Base, California are presently circling the earth in four different orbits. They have been launched in response to the requirements of military environmental research study projects which are concerned primarily with electromagnetic radiation from the sun, communications, the Van Allen radiation belts, engineering tests on space-vehicle materials, and a solar-cell power system.

Three Orbiting Vehicle Satellites (the OV1-17, 18 and 19), and one special satellite (the OV1-17A), carried 41 DoD experiments into the near-earth environment. The construction and operation of the OV1 satellites is under the management of Detachment 6 (LOOAR), Office of Aerospace Research, Los Angeles, Calif., which has provided a total of 21 satellites bearing the OV1 designation. General Dynamics/Convair builds the OV1 satellites and propulsion systems, and also acted as integrating contractor for this launch. The overall program manager for Air Force research satellites is the Office of Aerospace Research.

The launch of these satellites was accomplished by the Space and Missile Systems Organization (SAMSO), AFSC, Los Angeles, Calif., as part of a continuing mission by its Space Experiments Support Program to provide space flight for DoD experimenters.

The OV1-17 was orbited to measure incoming solar electromagnetic radiation and the reaction of this radiation with the earth's upper atmosphere. Seven of the 12 experiments aboard this satellite will provide a detailed study of incoming solar X rays and resultant density and composition changes, charged-particle production, and ultraviolet radiation produced in the region of the atmosphere 100 miles and higher. The remaining five experiments aboard the OV1-17 are individual experiments which will make electric-field and extremely low-frequency energy propagation studies, determine the usefulness of ionized meteor trails in the calibration of ground-based radars, and make engineering tests on space-vehicle materials and a solar-cell power system.

Sponsors of experiments aboard the OV1-17 are the Air Force Cambridge Research Laboratories (OAR), Aerospace Research Laboratories (OAR), Air Force Materials Laboratory (AFML), Air Force Systems Command, and the University of California for the Navy Air Systems Command.

The Naval Research Laboratory's "ORBIS-CAL II" experiment aboard the OV1-17A consists of two transmitting beacons which are being monitored by several ground-based stations to study unusual transmission of radio waves through the ionosphere. This "satellite" is in reality the last booster of the OV1-17, and is called the OV1-17 propulsion module. Because the propulsion module itself remains in orbit for a time, the "ORBIS-CAL II" experiment was attached to it; this resulted in an economical space vehicle.

Multiple experiments operating aboard the OV1-18 satellite will be used to make a detailed study of the characteristics of the ionosphere so important to the operation of many DoD communications, detection, and control and tracking systems. The earth's ionosphere consists of several layers of electrons and other charged particles blanketing the earth above 40 miles altitude. The upper ionosphere is all-important to the propagation of radio waves used for many military, as well as nonmilitary, purposes. The experiments in this package are designed to investigate specific aspects of the ionosphere which frequently subject the systems to anomalous or unusual effects.

The other experiments on OV1-18 will measure radio-wave interference at satellite altitudes, electric-field intensity and hazardous radiation.

AFML, the Aerospace Corp. (through AFSC), the University of

California (through NASC), and Lockheed Missiles and Space (through ARPA) are sponsoring the experiments aboard the OV1-18.

The OV1-19 has two major objectives: (1) to make a detailed study of events resulting in and sustaining trapped radiation in the Van Allen radiation belts; and (2) to study the hazards of incoming and trapped radiation to man. In order to meet these objectives, the satellite was placed in an orbit reaching as high as 3,000 nautical miles, well into the inner radiation belts. Seven experiments are being conducted in the trapped-radiation study, while five additional experiments on the OV1-19 spacecraft are devoted to determining what effects the radiation would have on man.

The OV1-19 experiments are sponsored by AFML, SAMSO, and the Aerospace Corp.

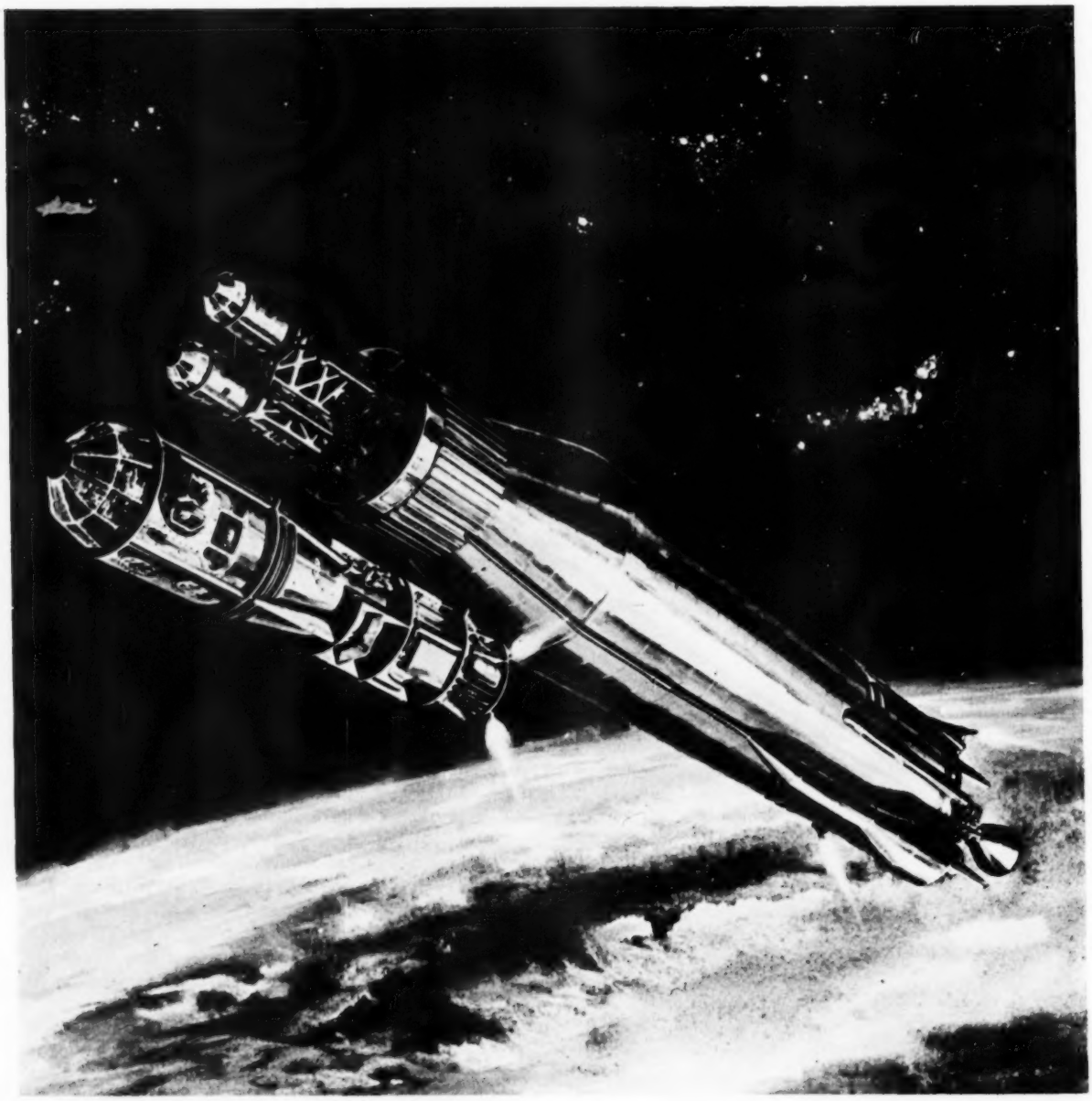


Figure 1. Artist's conception of the 18 March 1969 launch from Vandenberg Air Force Base, California. One of the Orbiting Vehicle Satellites is shown breaking away from the Atlas F booster.

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